AD-A093 507 HERIOT-WATT UNIV EDINBURGH (SCOTLAND) DEPT OF PHYSICS F/G 20/5
SUBMILLIMETER LASER AND FABRY-PEROT SPECTROSCOPY USING METALLIC--ETC(U)
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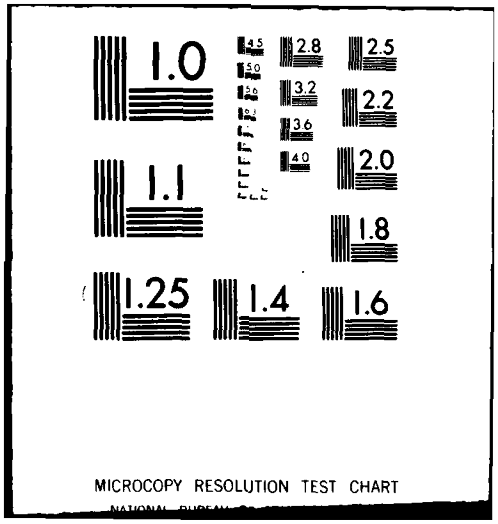

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R&D 2543-EE

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER ⑥

2. GOVT ACCESSION NO. AD A093507

3. RECIPIENT'S CATALOG NUMBER ⑨

4. TITLE (and Subtitle)
Submillimeter Laser and Fabry-Perot Spectroscopy Using Metallic Mesh .

5. TYPE OF REPORT & PERIOD COVERED
~~2nd~~ 1 Annual Technical Report no. 2,
1 Jun[illegible]79 — 31 May [illegible]80

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s) ⑩
Dr. C.R. Pidgeon
Mr. B.W. Davis

⑮

8. CONTRACT OR GRANT NUMBER(s)
DA-ERO-78-G-074

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Heriot-Watt University
~~Riccarton~~, Edinburgh, ~~U.K.~~ (Scot[illegible]

⑯

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
6.11.02A
1T161102BH57 03

⑰ 03

11. CONTROLLING OFFICE NAME AND ADDRESS
USARDSG-UK
Box 65, FPO NY 09510

⑪

12. REPORT DATE
May 1980

13. NUMBER OF PAGES
12

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

⑫ 14

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fabry-Perot Spectroscopy; Submillimeter Laser Spectroscopy; Metallic Mesh Spectroscopy; CO_2 Laser; Heterodyne Techniques

Micrometers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An optically pumped submillimeter laser has been designed and the laser resonator constructed. The objective was to produce a laser which could accommodate a wide range of waveguides and output coupling forms, yet still retain consistent performance over the whole range from 40 [illegible] to 1.2 mm. The performance expected was a large number of emission lines over the described range with output powers in excess of 1 mW. Experience from other submillimeter laser systems used led to the choice of a 25 mm I/D

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20. contd.

dielectric waveguide with a 5 mm diameter pinhole type output coupler as the basis of the optical resonator. A novel mirror translator system, in the form of a 'wobble stick', has been designed and successfully operated in the laser. Such power levels as described were achieved using the CO_2 pump laser described in the 1st Annual Technical Report.

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A two element Low Pass Blocking Filter which was designed and constructed for use in conjunction with the submillimeter laser has been successfully applied to help identify the 170.6 μm emission line from CH_3OH pumped with 9P36 CO_2 transition. The more powerful 118.8 μm emission line was effectively blocked, although still lasing, since the filter was external to the laser cavity.

B

Summary

An optically pumped submillimetre laser has been designed and the laser resonator constructed. The objective was to produce a laser which could accommodate a wide range of waveguides and output coupling forms, yet still retain consistent performance over the whole range from 40 μm to ∿ 1.2 mm. The performance expected was a large number of emission lines over the described range with output powers in excess of ∿ 1 mW. Experience from other submillimetre laser systems used led to the choice of a 25 mm I/D dielectric waveguide with a 5 mm diameter pinhole type output coupler as the basis of the optical resonator. A novel mirror translator system, in the form of a 'wobble stick', has been designed and successfully operated in the laser. Such power levels as described were achieved using the CO_2 pump laser described in the 1st Annual Technical Report.

A two element Low Pass Blocking Filter which was designed and constructed for use in conjunction with the submillimetre laser has been successfully applied to help identify the 170.6 μm emission line from CH_3OH pumped with the 9P36 CO_2 transition. The more powerful 118.8 μm emission line was effectively blocked, although still lasing, since the filter was external to the laser cavity.

Keywords: submillimetre laser; metallic mesh interference filters.

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Chapter I

An Optically Pumped Submillimetre Laser

1.1 Introduction

The optically pumped submillimetre laser was first described in 1970[+] and is now a commonly used source of coherent submillimetre radiation. The accidental coincidences between Infrared frequencies and Doppler broadened vibrational-rotational absorption lines of polar molecules have given rise to over 1000 submillimetre wavelengths ranging from tens to thousands of microns. The excitation of a particular rotational level within some vibrational level with an I.R. frequency is a selective process giving the opportunity of an efficient laser system. The quantum efficiency can be as high as 30%, but such high efficiencies were not achieved until the advent of the waveguide type laser, with the original optically pumped submillimetre laser, being of the open resonator type and only yielding quantum efficiencies of a few percent or less.

Lasing action occurs between adjacent rotational levels within some vibrational state providing certain conditions are met. One such condition is that the molecule should be polar, and that the permanent dipole moment μ should be ≈ 1 Debye or larger, since the transition probability is directly proportional to the permanent dipole moment. The close coincidence between I.R. source and absorption line is typically less than $\sim 0.01\ \text{cm}^{-1}$ (50 MHz), although this can be relaxed with high pump powers.

The pressure of the gas used in submillimetre optical pumping has been found to be within the range, 30 mT - 300 mT and such low operating pressures result in the vibrational-rotational absorption lines being broadened by a Doppler type process. Such pressures are required to avoid rapid thermalization of the rotational levels, a process which is proportional to pressure, and is given by collisions occurring at a rate $\tau_{\Delta J}^{-1}$ (λ) and occurs in all vibrational levels.

Another molecular relation rate Γ, shows the rate at which molecules in some upper vibrational states, relax to a ground state. This rate has been shown, at the pressures used to be largely due to collisions with the resonator walls, which is dependent on the molecular diffusion rate across the resonator.

The relative values of λ and Γ are critical for a population inversion to be sustained, and Γ must be sufficiently rapid to avoid a build up of population in the lower laser level, which in turn

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[+] T Y Chang, T J Bridges, Opt. Commun., Vol 1, No. 9, p. 423, (1970).

would result in the destruction of inversion. The cavity design has been shown to effect the vibrational relaxation rate Γ, with the waveguide type cavity greatly enhancing Γ.

The laser was thus constructed as a waveguide type but with the possibility of modifying to an open resonator type at a later stage.

1.2 The Submillimetre Laser Design

A laser which could easily accommodate a wide range of waveguides and output coupling systems, but still retain performance with submillimetre powers in excess of 1 mW over the whole submillimetre range, was required and the following is a description of the laser so designed.

From previous work it was found that the reflectors at the input and output ends of the laser could easily be aligned parallel with an external HeNe laser. This relaxed the design task since no serious problems would be experienced in translating one of the reflectors against a pressure difference (atmospheric outside the cavity and typically 10^{-1} Torr inside). Other designs have been seen to use a set of flexible bellows loosely connected to the output coupler, with the bellows providing the required spring effect for a smooth translating motion for the output coupler, but this can be extremely costly and for this reason an alternative was investigated in the form of a 'wobble stick', and is described later.

The main criteria for the laser can be given as:

(1) Simple construction.
(2) Flexibility in waveguide and reflector choice.
(3) Output coupling method to be such that all known systems of coupling could be introduced.
(4) Sealed or flowing gas operation.

The condition that the output coupling method should be flexible led to the input mirror being the one which was translated (this being necessary to tune the cavity) and the output mirror being 'fixed'. The problem, however, of a focussed CO_2 beam being on axis with the submillimetre laser, suggested that if a direct, on axis mirror drive system was used then the possibility of danger to the operator was high unless a remote drive system was incorporated. The alternative was to use a 'wobble stick' with side entry into the laser as shown in Fig. (1.1). This arrangement has the useful characteristic that a movement of say x μm appears as a movement of the translator of ∿ x/3 depending on the ratio of the distances XA to XB. Stainless steel bellows (1) were used to give a spring motion. A roller ball bearing (2) ensured that frictional forces between the micrometer drive and the swinging arm (3) were kept to a minimum. The other end of the swinging arm made contact with a translator, onto which the input mirror was fixed, with a second roller ball bearing (4). A pushing motion is experienced by the translator for a pulling motion by the rotating flange (5), attached to the micrometer. The motion of the translator was over two tracks constructed out of ball bearings laid in tracks defined by stainless steel bars.

Vacuum integrity of the laser was maintained with standard muff coupling type 'O' ring seals at all joints. This has been effective, in that the ultimate vacuum attainable with a diffusion pump is $\sim 10^{-5}$ Torr. No degradation of the 'O' rings, which are all Viton has been observed over the period of operation.

The design of the resonator is outlined in Fig. (1.2), with the whole laser being mounted on a rigid aluminium channel (A). At each end of the channel, two aluminium blocks (B) and (C) were fixed securely onto support brackets (E). One of the brackets is rigidly fixed to the base with the other being free to slide along the laser axis. This freedom of motion was necessary to free the structure from any distortions resulting from any thermal effects. The amount of thermal motion is kept to a minimum with the use of three invar bar supports (D) to separate the end blocks. The low coefficient of expansion of invar makes it a suitable material. Additional support for the 1.5 metre bars was provided by support flanges at (1) and (2).

The aluminium blocks (B) and (C) were bored out to give cavities in which the output and input reflectors could be housed. The input mirror, as discussed, was translatable by $\sim$ 5 mm, and this was in block (C). The output mirror support was rigidly fixed internally to block (B). Both mirrors could be easily adjusted with the laser cavity unevacuated.

An outer vacuum jacket was provided by means of a glass tube, 84 mm diameter, and was fixed by muff type coupling seals to the two end blocks. The size of the outer vacuum envelope, linked with the large coupling mirrors (50 mm diameter) enables waveguides of up to $\sim$ 48 mm I/D to be used in the system. Alternatively an open resonator laser could easily be produced from such a design. The pump powers required for efficient pumping of large bore waveguides were in excess to those available with our cw CO_2 lasers.

Vacuum pumping was from a port in block (C) using a diffusion pump, although this was later changed to an ion pump system. The change was necessitated because of the instabilities caused by the backing rotary pump. Operation with the ion pump system had no such problems and the results presented are for such a system. The laser gas inlet is through a port in block (B), at the opposite end of the laser. Provision for an internally mounted optoacoustic facility is provided with a vacuum lead through positioned below the gas inlet.

The final vacuum seals are provided by flat end flanges which are clamped onto the end blocks with 'O' ring seals. These flanges support the input and output windows, NaCl and T.P.X. respectively. The output window was of a large enough diameter so as not to impede any of the diverging radiation emerging from the hole coupler.

The input mirror had a centrally drilled hole of 2 mm diameter, through which the CO_2 radiation was injected, although this diameter is not too critical. The output hole was 5 mm diameter, again centrally drilled. A 25 mm I/D dielectric waveguide (F) was held coaxially inside the outer glass envelope (G). The waveguides are 1.5 metres long resulting in a minimum cavity length of the same and a maximum cavity length of $\sim$ 1.505 metres.

With the system of end blocks giving housing for the reflectors it will be a relatively simple task to remove one completely and install a Michelson type mesh coupler if required. Such an arrangement would be supported by the end flange (E) in a similar fashion to that of the original design.

1.3 Laser Operation

The only changes to the original design were to the translator mechanism. The stainless steel bellows were a replacement for brass bellows which began to work harden after 1-2 months of operation. The swing arm was also noticeably flexing and was subsequently replaced by a larger diameter bar. With the described changes a satisfactory tuning method had been devised.

Using the CO_2 laser described in the first Annual Technical Report a series of tests on the submillimetre laser were carried out and the results of the laser performance, for a range of laser gases, are shown in table (1.1).

The original objective of laser power in excess of 1 mW over the whole submillimetre range has been achieved. For wavelengths greater than 500 μm, metal brass guides were used (the losses in dielectric guides being excessive for $\lambda \gtrsim 500$ μm). The brass guide dimensions were as for the original dielectric guide.

Chapter 2

Application of Mesh Techniques to a Submillimetre Laser

2.1 Introduction

The optical pumping of CH_3OH with the 9P36 CO_2 laser transition has been reported to result in three submillimetre laser emissions at 118.8 μm, 170.6μm and at 392 μm. The 118.8 μm line, however, is the more powerful of the three resulting in the remaining two being not so commonly reported. Identification of weaker emissions, while in the presence of a stronger line is always difficult and a method to ease this task has been devised. This method is to use a blocking filter, based on metallic mesh, to block the more powerful line external to the cavity, making the identification of other lines easier.

2.2 The Use and Design of a Blocking Filter

A simple two or three element device, using capacitive mesh and supported by two invar clamping rings was investigated. Using established design techniques* a two element stack of 90 μm meshes separated by a single spacer of 20 μm thickness was constructed and the resulting profile is shown in Fig. (2.1). A good cut-off edge is seen but with incomplete rejection, but this was acceptable since it was only important to ensure that the filter did not have any transmission at 118.8 μm. The filter was measured with a Michelson type Fourier Transform Interferometer, and showing transmission levels of ∿ 80% at 392 μm and ∿ 15% at 170.6 μm.

A large number of modes were observed with the lasing operating and the most obvious laser line was the 118.8 μm line. The filter was placed immediately in front of the detector which had the effect of suppressing the powerful line yet on tuning the cavity strong modes still appeared.

An external mesh scanning Fabry-Perot interferometer was used to identify the wavelength of these strong modes, and after repeated tests the presence of the 170.6μm line was confirmed, although no 392 μm line could be seen. The use of a dielectric guide is thought to be a contributing factor in the difficulty in identifying the 392 μm line, and the use of a metal guide, with its lower losses is suggested. The power level of the 170.6μm was measured as ∿ 2 mW compared with ∿ 20 mW for the 118.8 μm line.

A method by which one laser line can be suppressed whilst allowing another to be easily identified has been described. This technique could easily be applied to other wavelengths since such filters are easily designed and constructed.

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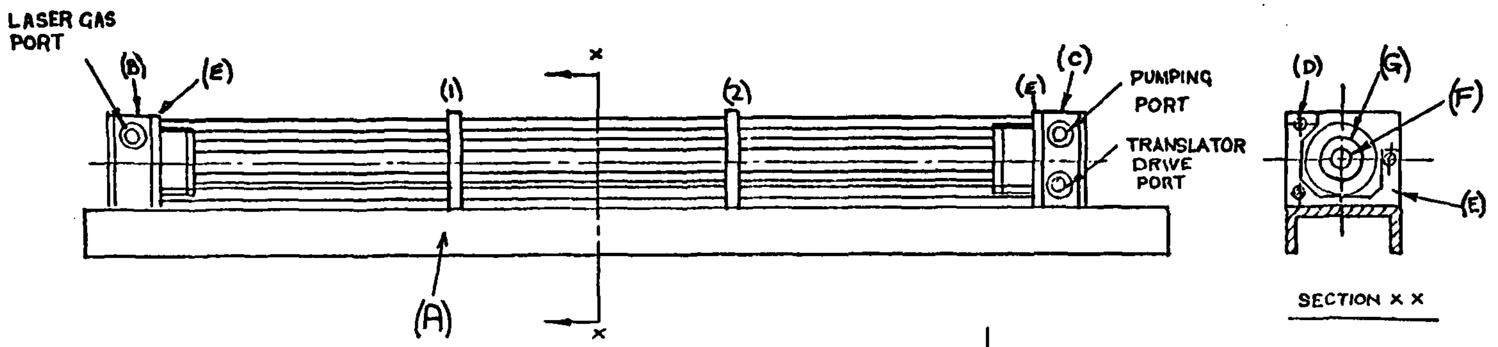
* G D Holah, J P Auton, Infrared Physics, Vol. 14, p. 217, (1974).

Fig. 1.2 Schematic diagram of laser



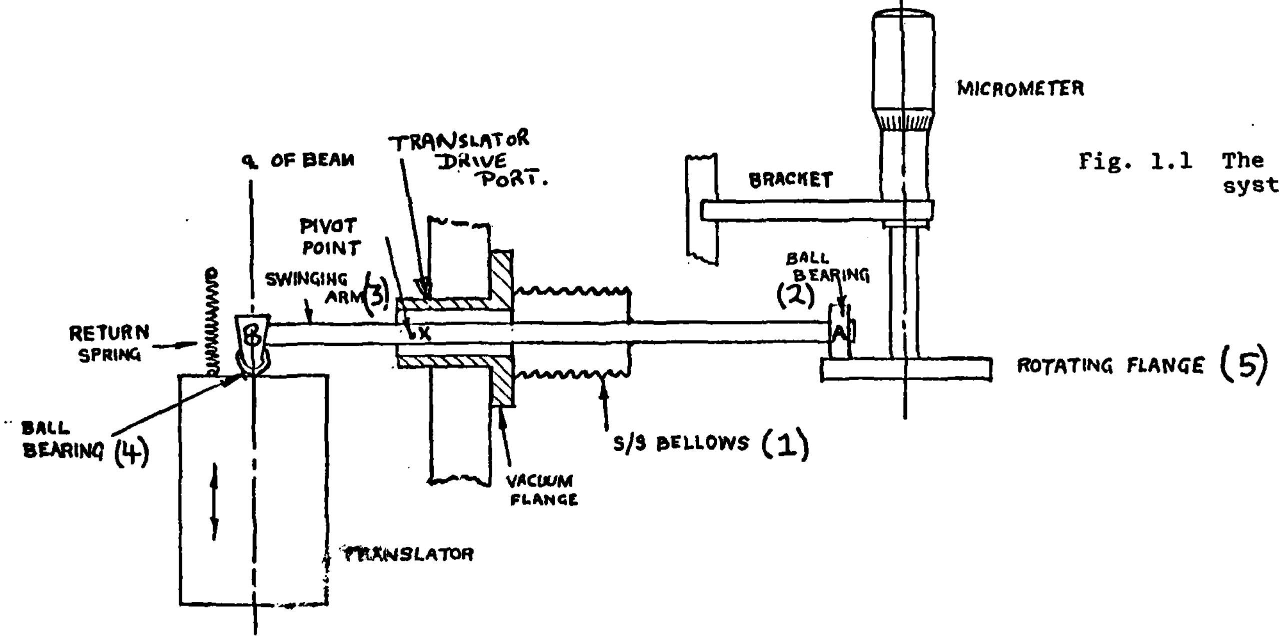


Fig. 1.1 The mirror translator system

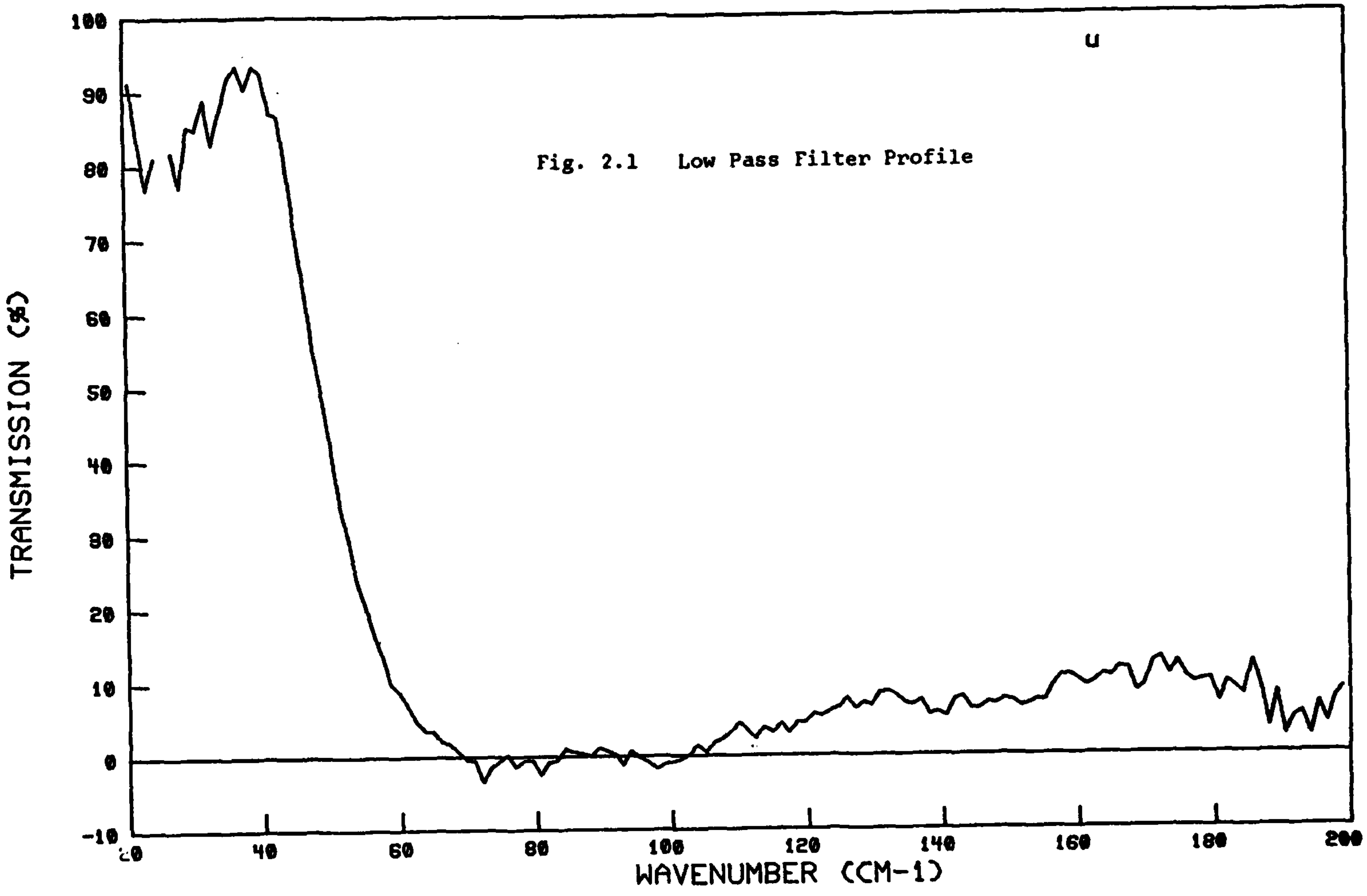


Fig. 2.1 Low Pass Filter Profile

Laser Gas	CO_2 line	Submillimetre λ (μm)	cw submillimetre power (mW)
CD_3OD	10R18	41	18.5
CH_3OH	9R18	65	0.93
$C_2H_4(OH)_2$	9P34	70.1	5.3
CH_3OH	9P34	70.6	5.3
CH_3OH	10R16	71	1.6
$C_2H_4(OH)_2$	9R10	95.8	4.2
CH_3OH	9R10	96.5	15.0
$C_2H_4(OH)_2$	9P36	118.0	15.9
CH_3OH	9P36	118.8	20.0
CH_3NH_2	9P24	148.5	0.9 *
CH_3OH	10R38	164	4.56 *
CH_3OH	9P36	170.6 (with blocking filter)	2
CH_3OH	9R18	186	3.2 *
CH_3OH	10R38	246	0.74
HCOOH	9R16	401	1.14
HCOOH	9R20	428	1.60 *
HCOOH	9R18	441	5.0 *
CH_3I	10P18	447	3.4 *
CH_3F	9P20	496	1.14 *
HCOOH	9R26	512	0.96 *
CH_3OH	9P16	570	5.64 *
CH_2CF_2	10P24	663	0.68 *
CH_2CF_2	10P22	890	0.40 *
$^{13}CH_3F$	9P32	1222	6.0 *
			* metal guide

Table 1.1 Submillimetre laser performance (with normal $^{12}C^{16}O_2$ pump laser)